Reeves, et al., in Substorms 3, ESA SP-339, 689-694, 1996.

# Los Alamos Space Weather Data Products: On Line and On Time

G. D. Reeves, R. D. Belian, T. C. Cayton, R. A. Christensen, M. G. Henderson, and P. S. McLachlan

Los Alamos National Laboratory, Mail Stop D436, Los Alamos, NM 87545, USA, reeves@lanl.gov

## ABSTRACT

Substorm injections near geosynchronous orbit are a very reliable indicator of substorm activity. In addition, like Pi2 data or indices like AE, geosynchronous energetic particle data are available nearly continuously and for a long period of time. Energetic particle data from geosynchronous orbit are now one of the most common data sources used to identify substorm timing, development, amplitude, and characteristics. This paper presents an overview of geosynchronous energetic particle data obtained from a series of Los Alamos energetic particle instruments that have recently been made available on the World Wide Web for substorm studies. Los Alamos geosynchronous energetic particle measurements began in 1976 and are still ongoing. Typically data are available simultaneously from three geosynchronous satellites. Two generations of instruments have flown – the Charged Particle Analyzer (CPA) and the Synchronous Orbit Particle Analyzer (SOPA). Both instruments measure electrons and ions with energies from tens of keV to tens of MeV. The data which have been made available on-line consist of 1-spin (approximately 10-second) averages or 1-minute (approximately 6-spin) averages. This paper includes a brief description of the data holdings, instructions for accessing digital data and summary plots, and instructions for accessing other reference material related to the data via the World Wide Web.

## 1. INTRODUCTION

Nearly thirty years ago Explorer 45 observed rapid increases in energetic particle fluxes in the magnetosphere that were associated with "magnetic bays" [Ref. 1]. Today these rapid increases are known as substorm injections and a large number of studies have been published on their characteristics and on their association with other substorm phenomena.

Figure 1 (adapted from [Ref. 2]) shows the characteristics of a "classic" substorm injection. Satellite 1982-019 was located very near local midnight at the time of the substorm injection at 0444 UT. Prior to the substorm injection one can observe a decrease in the energetic electron fluxes which is associated with the substorm growth phase [Ref. 3]. The dropout is due to the stretching of the magnetic field lines during the substorm growth phase which then magnetically connect the satellite to the lower energetic particle fluxes in the more distant tail. At substorm onset the particle fluxes do not simply recover to

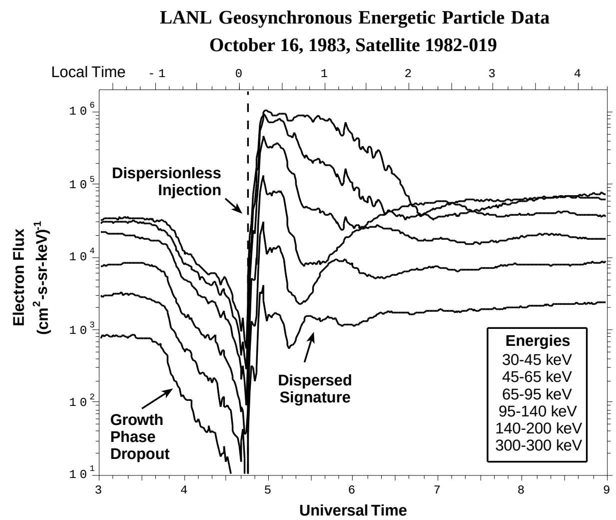


Figure 1: A substorm injection on October 16, 1983 that shows the "classic" signatures observed at geosynchronous orbit.

their previous levels but rather are enhanced by an order of magnitude or more. This enhancement is due to acceleration of the particles and is referred to as the substorm injection. In this case electrons of all energies between 30 and 300 keV were enhanced simultaneously. This is referred to as a "dispersionless" injection and it indicates that the satellite was within the "injection region". Dispersionless substorm injections are one of the easiest signatures of substorm onset to identify and to time. They usually occur within a few minutes of other substorm onset indicators such as Pi2 pulsations, magnetic bays, and auroral breakup activity.

Substorm injections are limited in their spatial extent (e.g. [Ref. 4] and [Ref. 2]) and therefore observation of a dispersionless substorm injection depends on having a satellite in the right place at the right time. Fortunately, substorm injection signatures can be observed even when a satellite is outside the injection region. After being injected the charged particles gradient-curvature drift with electrons drifting east and ions drifting west. The gradient-curvature drift velocity is proportional to energy so the injected particles become dispersed in energy. A dispersed injection signature can also be observed in Figure 1. Dispersed injection signatures can often be observed at large distances from the injection region. In the case of Figure 1 the electrons from the first injection have drifted all the way around the earth to be observed by the same satellite again. These are known as "drift echo" events (e.g. [Ref. 5] [Ref. 6], [Ref. 7]).

Substorm injections have been observed by a number of spacecraft – including CRRES and AMPTE/CCE – but they have most commonly been observed at geosynchronous orbit in part because of the large number of satellites that have operated there. One of the most frequently used sources of geosynchronous energetic particle data for substorm studies is the Los Alamos National Laboratory energetic particle database. The use of this data set has increased dramatically in the last several years both because of an increasing awareness of its importance and because of its increasing ease of availability thanks to improving information-handling technology. As an example of how important the data have become for substorm studies we note that over twenty of the presentations at the Third International Conference on Substorms included Los Alamos energetic particle data.

In addition to their inherent value for substorm research, the *availability* of the data also contribute to their wide-spread use. Los Alamos began collecting energetic particle data at geosynchronous orbit in 1976 and the program has been in continuous operation since then. Since 1979 there have typically been three satellites operating simultaneously, providing good local time coverage. As with magnetometer data or indices like AE the continuity and coverage of the data are important because, for any given substorm, there is a high probability that there will be geosynchronous energetic particle data available. Furthermore, the data are collected in real time and are made available on line within about 24 hours which makes them particularly well suited to space weather applications.

In this paper we do not attempt to review the existing literature on substorm injections. Nor do we present new scientific results. Rather, this paper should be viewed as an introduction to the Los Alamos geosynchronous energetic particle data base for those readers who would like to make use of it in the future. The paper includes a description of the current data holdings and instructions for accessing the data using the graphical interface to the internet known as the "World Wide Web". The starting point for access to the database is the Los Alamos Energetic Particle (LANL EP) "Home Page" at `http://leadbelly.lanl.gov/lanl_ep_data/`.

## 2. THE DATA

Geosynchronous orbit is a circular orbit located at a geocentric distance of approximately 6.62 $R_E$ (42,000 km) where the orbital period is approximately 24-hours. In that orbit a spacecraft will stay "fixed" above a particular geographic longitude. A spacecraft at the geographic equator can be up to ±11° off the magnetic equator due to the tip of the earth's dipole with respect to its spin axis. Thus geosynchronous satellites at different geographic longitudes will be at slightly different magnetic latitudes and therefore slightly different L-shells. In addition the asymmetries and temporal variation of the earth's magnetic field can also make a geosynchronous satellite sample different magnetic L-shells. However, the variation in L is typically quite small and, compared to an elliptically orbiting satellite like CRRES, geosynchronous satellites are essentially fixed at L=6.6.

As part of an ongoing program the geosynchronous satellites which carry Los Alamos energetic particle instruments are referred to by their unimaginative and unromantic International Satellite Designator Numbers (ISDN). An example is satellite 1989-046. The first four digits refer to the year of launch. A given satellite such as 1989-046 might be operated at a single geographic longitude for its entire lifetime or it might be moved to a different longitude according to the needs of the mission. In general though, one satellite has operated near 70° W. Longitude, one has operated between 130° and 170° E. Longitude, and one has operated between 30° and 70° E. Longitude. Other longitudes have been covered at various times and for various amounts of time.

Los Alamos has flown two generations of energetic particle detectors at geosynchronous orbit. The Charged Particle Analyzer (CPA) instrument was flown on satellites from 1976 to 1987 and one or more CPA-equipped satellites operated through 1995. The Synchronous Orbit Particle Analyzer (SOPA) was flown on satellites beginning in 1989. Four SOPA-equipped satellites have been launched so far. Typically data are received from three or four satellites simultaneously. Nominal data coverage is 24-hours per day but data gaps do exist. Frequently a data gap on one satellite is due to switching ground receivers from that satellite to another satellite in the constellation. (See Figure 3.) From 1989 through 1995 data are typically available from both CPA-equipped satellites and SOPA-equipped satellites.

Although the CPA and SOPA instruments are similar there are some differences. CPA measures electrons from 30 keV to 2 MeV in 12 energy channels. It measures protons from approximately 75 keV to approximately 200 MeV in 26 energy channels. The energy thresholds for protons are "approximate" because there is some variation from one spacecraft to another. For example the nominal lowest energy proton threshold varies from 70 keV on spacecraft 1984-037 to 147 keV on spacecraft 1977-007. Six "low energy" electron channels are measured with five telescopes at angles of 0°, ±30°, and ±60° from the spin plane while the remaining measurements are made with single-look direction telescopes mounted at 0° with respect to the spin plane (referred to as the "belly band"). More detailed information on the CPA can be found in [Ref. 8] or can be accessed through the LANL EP Home Page as described below.

The SOPA instrument measures electrons from 50 keV to greater than 1.5 MeV in 10 energy channels and protons from 50 keV to 50 MeV in 12 channels. (In addition there are ten channels for heavy ions including alpha particles, Carbon, Nitrogen, Oxygen, and others.) Protons and electrons are measured together using three telescopes mounted at $0°$, $30°$, and $-60°$ with respect to the spin plane (belly band). More detailed information on the SOPA instrument can be found in [Ref. 9] or through the LANL EP Home Page.

Spacecraft carrying both generations of instruments (CPA and SOPA) are actively controlled such that the spin axis of the satellite points continuously toward the center of the earth. Therefore the nominal dipole magnetic field direction is approximately perpendicular to the spin axis. In that configuration complete pitch angle coverage is obtained for all electrons and ions each spin of the spacecraft (about 10.24 seconds). When the field becomes inclined and is no longer perpendicular to the spin axis excellent pitch angle coverage is still obtained for all SOPA channels (from 3 telescopes) and from the six "low energy" CPA channels (from 5 telescopes) while the other CPA measurements are limited in pitch angle according to the inclination of the field. This limitation should be remembered when analyzing spin-averaged data.

In addition, satellites carrying SOPAs also carry the Energy Spectrometer for Particles (ESP) instrument [Ref. 10] which measures electrons from 0.7 to 26 MeV in 6 channels and protons from 11 to greater than 20 MeV in three channels. Those data are not yet included in our on-line database and will not be discussed further in this publication.

## 3. THE LANL EP DATABASE

Digital data have been stored on-line using a SUN workstation and 12 GB of hard disk storage. The name of the workstation is `leadbelly.lanl.gov` and its internet node number is 128.165.207.108. Leadbelly is named after the great blues pioneer Huddie Ledbetter, better known as Leadbelly [`http://leadbelly.lanl.gov/leadbelly.html`].

A single data file is stored for each satellite for each day. By convention files are named with the date (Universal Time) and International Satellite Designator Number. The date is in YYMMDD format so a file for November 2, 1991 for satellite 1989-046 will be called `911102_1989-046`. A file extension may be added to indicate how the data were processed. For example, `911102_1989046.flux.sum`. The data are stored as ASCII text files which have then been compressed with the `gzip` utility. Each file includes ephemeris information. The first column is universal time (in decimal hours), followed by geographic latitude ($-90°$ to $+90°$), geographic longitude (- 180° to +180°), geocentric radius (in $R_E$), and count rates (counts/second) for each energy channel. The data may be processed to extract only certain energy channels, to convert count rates to flux, or to sum sets of energy channels.

Two sets of data files are archived. From 1989 to the present the raw telemetry data were stored on optical platters. Those data have been reprocessed to produce 1-spin ($\approx$ 10-second) averages. From 1979 to 1989 1-minute averages were stored along with the raw telemetry data on magnetic tape. Those data have been reprocessed to produce 1-minute average data files in the same format as the 10-second data files. Over 6,000 of the original magnetic tapes are being reprocessed to produce 10-second averages to replace the 1-minute averages and to fill in 1976 to 1979 when no averages were archived. Currently 10-second averages have been produced for 1976 through 1980 and for 1986 (the PROMIS period which includes coverage by the Viking auroral imager) in addition to all the data from 1989 onward.

New data are acquired in real time and can be viewed using a continuously-updating X-windows display. The data are also processed into 10-second averages at approximately 0200 UT on a daily basis. Summary plots are made at that time and both digital data and summary plots are put on-line, typically within one hour. Therefore data for the previous 24-hours of universal time can be accessed through the web server on `leadbelly.lanl.gov` within about three hours.

### 3.1. The Energetic Particle Home Page `http://leadbelly.lanl.gov/lanl_ep_data/`

All of the data and summary plots described here are available electronically over the internet. We have chosen to use the graphical interface and server protocol known as the World Wide Web (or simply the Web) as the primary means for accessing those products. The web server is also known as `leadbelly.lanl.gov` and the Universal Resource Locator (URL) is `http://leadbelly.lanl.gov/`.

The Los Alamos Energetic Particle "Home Page" is located at;

`http://leadbelly.lanl.gov/lanl_ep_data/`.

Figure 2 shows how the LANL EP Home Page appears on a typical web browser. The data on the server are currently organized into five areas: 1) access to digital data and plots that can be downloaded to the users machine, 2) an on-line archive of summary plots that can be browsed to identify interesting events, 3) a description of campaigns and projects that use LANL energetic particle data, 4)

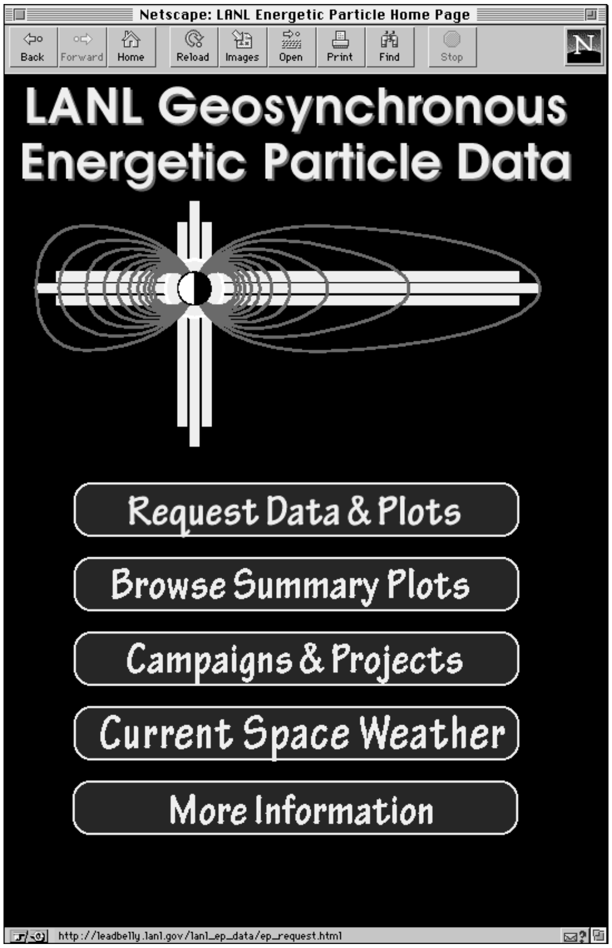


Figure 2: The Los Alamos Energetic Particle Home Page

"Current Space Weather" that illustrates the most recent observations from geosynchronous orbit, and 5) "More Information" which includes information about the satellites, the CPA and SOPA instruments, and about the database itself. It also includes information about the energetic particle team, and a bibliography of publications which use the LANL energetic particle data.

The functions that allow the user to request data and to browse summary plots will remain fixed features of the LANL EP server and their URLs will be left unchanged. They are described in more detail below. The other functions contain supplemental information and may be re-organized as more information is put on line.

### 3.2. Requesting Digital Data
`http://leadbelly.lanl.gov/lanl_ep_data/ep_request.html`

Digital data are stored as compressed text files with ephemeris and count rates. Typically the data need to be processed before they are useful to the average user. Therefore we have established a request system. The first part of the request system is a World Wide Web form. To request data you specify information such as your name and e-mail address, the date and times you want data for, what satellites, what energy channels, the time resolution required, and whether you want flux units or count rates. The request form generates an input file to a program that actually processes the data. Processed data are put in a unique directory for each request. One data file is produced for each satellite and each day requested. The data are provided as text files (not compressed) and include ephemeris as well as fluxes or count rates. The requester is notified by e-mail when the data are ready and can download the data by anonymous FTP or through a Web interface.

The data are received at Los Alamos in real time but are processed daily. Therefore data are typically available within 24 hours of when they were acquired. The system is currently optimized to request as little as a few minutes of data or as much as several weeks worth of data. Long-term surveys (months or years worth of data) currently require too much processing power for the on-line system. In the future, hourly and daily averages will be produced and put on-line for long-term studies.

### 3.3. Viewing Summary Plots
`http://leadbelly.lanl.gov/lanl_ep_data/summary_plot_chose.html`

While access to digital data is often essential for a study or as input to a model, it is often more convenient to quickly view a summary plot of the data. Summary plots can be useful to determine what satellites were providing data at a particular time, where they were located, and whether something interesting was happening. A quick check of a summary plot can let you know whether it is even worthwhile requesting digital data.

One key to making summary plots useful is that it must be quick and easy to view them, to find the date you are interested in, and to page through plots as one would with hard copy. For this to be practical, the plots were pre-generated and saved as GIF images which are viewable by a web browser. Currently only one type of summary plot has been produced. An example is shown in Figure 3. These summary plots highlight substorm injection activity. The plot shows 30-300 keV (for CPA) or 50-315 keV (for SOPA) electron fluxes over 24-hours of universal time. The plot has stacked panels with one panel for each satellite. The time at which the satellite passed midnight is indicated with a vertical bar. Substorm injections show up most clearly in the electron fluxes when the satellite is near midnight or in the dawn sector (e.g. in Figure 3, ≈1530 UT, for satellite 1989-046). Drifting injections of electrons can be seen at other local times (e.g. in Figure 3, ≈1530 UT, for satellites 1987-097 and 1990-095).

Using buttons the user can page through plots, forwards or backwards, from one day to another or the user can choose the year, month, and day of interest. Additional information and links to the other Los Alamos energetic particle web pages are also provided.

As with the digital data, summary plots are produced on a daily basis and are generally available 24-hours after the data were acquired. Other useful summary plots are envisioned. Summary plots of "low energy" protons in a format similar to those already available for electrons will be available in the near future. For higher energies, monthly and/or yearly summary plots will be made available for relativistic electron enhancements (e.g. >2 MeV) and for solar energetic particle events (e.g. >10 MeV). Several data synthesis products are being developed. A Geosynchronous Electron Flux (GEF) index has been developed and is available for testing. The GEF index is a single-variable time series of 50-300 keV electrons from whatever satellite is closest to midnight. This index is useful for comparison with other indices such as AE or Dst and for more complex analyses that are not amenable to input from multiple energy channels and from multiple satellites. A complimentary Global Geosynchronous Synthesis model which interpolates between satellites for full local time coverage is also being developed.

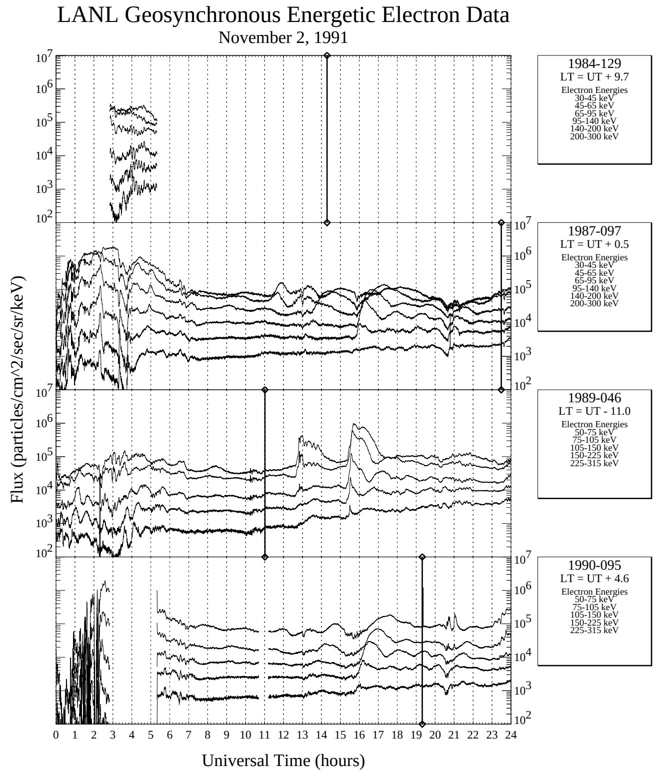


Figure 3: A typical electron summary plot. These plots are viewable as GIF images with any Web browser. There is one plot for each day from 1979 to the present. Additional hypertext buttons allow the user to page through plots, to select other dates, or to get additional information about the plots and the data.

## 4. CONCLUSIONS

Increasingly substorm research depends on the synthesis of data from many observation points in the magnetosphere. Timely and easy access to data from a variety of sources can greatly facilitate those studies. One source of data that has proven to be of significant value in identifying, timing, and characterizing substorms is energetic particle measurements from geosynchronous orbit.

The Los Alamos energetic particle team has developed an on-line database of energetic particle data from geosynchronous orbit which is accessible over the internet. Digital data can be requested and downloaded on-line. Summary plots can be also be viewed on-line. In addition much of the information needed to properly interpret the data can also be found on-line. Only a portion of that information could be included in this brief introduction to the data system. We also note that, while much of the data system can be considered complete, many more useful features will be added as they are developed. Readers are encouraged to browse the database and web pages for themselves and to provide us with comments and suggestions.

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